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FLAMMABLE MATERIALS: A LECTURE DEMONSTRATION

By M. G. Zabetakis and H. H. Engel

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FLAMMABLE MATERIALS: A LECTURE DEMONSTRATION[1]

by

M. G. Zabetakis[2] and H. H. Engel[3]

INTRODUCTION AND SUMMARY

This publication contains highlights of a 4-hour lecture and demonstration by the Bureau of Mines on the fire and explosion hazards of flammable liquids and solids, oxidizing materials, corrosive liquids, and compressed gases.

The authors first presented this material as part of a 2-week course given to officers and enlisted men at the U.S. Coast Guard's Dangerous-Cargo Handling School, established at Fort Eustis, Va., in 1959.

The Bureau was asked to present the lecture and demonstration because of the extensive experience of its researchers in handling certain harardous commodities.

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DEFINITIONS

A dangerous article is defined in 46 CFR,[4] section 146.03-8, as one falling within any of the following classifications:

1. Explosives.
2. Flammable liquids
3. Flammable solids and oxidizing materials.
4. Corrosive liquids
5. Compressed gases.
6. Poisons.
7. Hazardous articles.
8. Ships' stores and supplies of a dangerous nature.

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[1] Work on manuscript completed January 1961.

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[3] Safety representative, Health and Safety District B, Bureau of Mines, Pittsburgh, Pa.

[4] Code of Federal Regulations, Title 46 - Shipping: U.S. Government Printing Office, Washington 25, D.C.

These classifications are discussed in 46 CFR 146 and 147. In this paper, the properties of flammable liquids, flammable solids and oxidizing materials, corrosive liquids, and compressed gases will be considered in some detail. However, before proceeding it would be well to review the applicable definitions of each of the articles and related terms given in 46 CFR 146.

A flammable liquid is defined (sec. 146.21-1) as any liquid that gives off flammable vapors (that is, vapors that when mixed with air can be ignited by a suitable source, such as a spark or flame) at or below a temperature of 80° F.; any liquid that gives off flammable vapors at or below a temperature of 150° F. and above 80° F. is classed as a combustible liquid (sec. 146.26-1). The lowest temperature at which such liquids give off flammable vapors in air at atmospheric pressure is known as the flashpoint (sec. 146-03-14). At this temperature, the flammable vapor concentration in air corresponds roughly to the lower or "fuel-lean" limit of flammability (or explosibility). Most flammable (and combustible) liquids form explosive concentrations with air over a specific range of mixture compositions, the explosive range (sec. 146.03-10). Mixtures containing less fuel vapor than the lower or "fuel-lean" limit of flammability are nonflammable; those containing more fuel vapor than the upper or "fuel-rich" limit of flammability are also nonflammable. Mixtures containing an amount of fuel vapor between these concentration extremes (that is, between the limits of flammability) are flammable.

As a lower limit-of-flammability mixture, or a lower limit mixture, contains the least amount of fuel vapor capable of forming an explosive mixture and as the flashpoint is the lowest temperature at which enough fuel vapor is given off to form an explosive mixture, it is not surprising to find that these two quantities are related. To understand the significance of this relationship, one must consider for a moment still another property of liquids and solids--their vapor pressure.

Vapor pressure is mentioned briefly (sec. 146.03-37) as a factor that governs, in part, the tendency of a liquid to assume the vapor state. The vapor pressure of a given substance at a specified temperature is the pressure that would be developed by its vapors in a closed container. The vapor pressures of a number of combustibles are listed in table 1 and shown graphically in figure 1; vapor pressure is plotted as ordinate (vertical axis) against the temperature as abscissa (horizontal axis). The unit of vapor pressure in figure 1 is millimeters (mm.) of mercury; this unit can be changed to inches of mercury, pounds per square inch absolute (p.s.i.a.) or pounds per square inch gage (p.s.i.g.) by use of the following:

$$\text{Inches of mercury} = \frac{\text{mm. of mercury}}{25.4},$$

$$\text{p.s.i.a.} = \frac{\text{mm. of mercury}}{760} \times 14.7, \text{ and}$$

$$\text{p.s.i.g.} = \text{p.s.i.a.} - 14.7 = \left(\frac{\text{mm. mercury}}{760} - 1\right) 14.7.$$

Only pressure values above 760 mm. (14.7 p.s.i.a.) will yield positive values of pressure when expressed in terms of pounds per square inch gage.

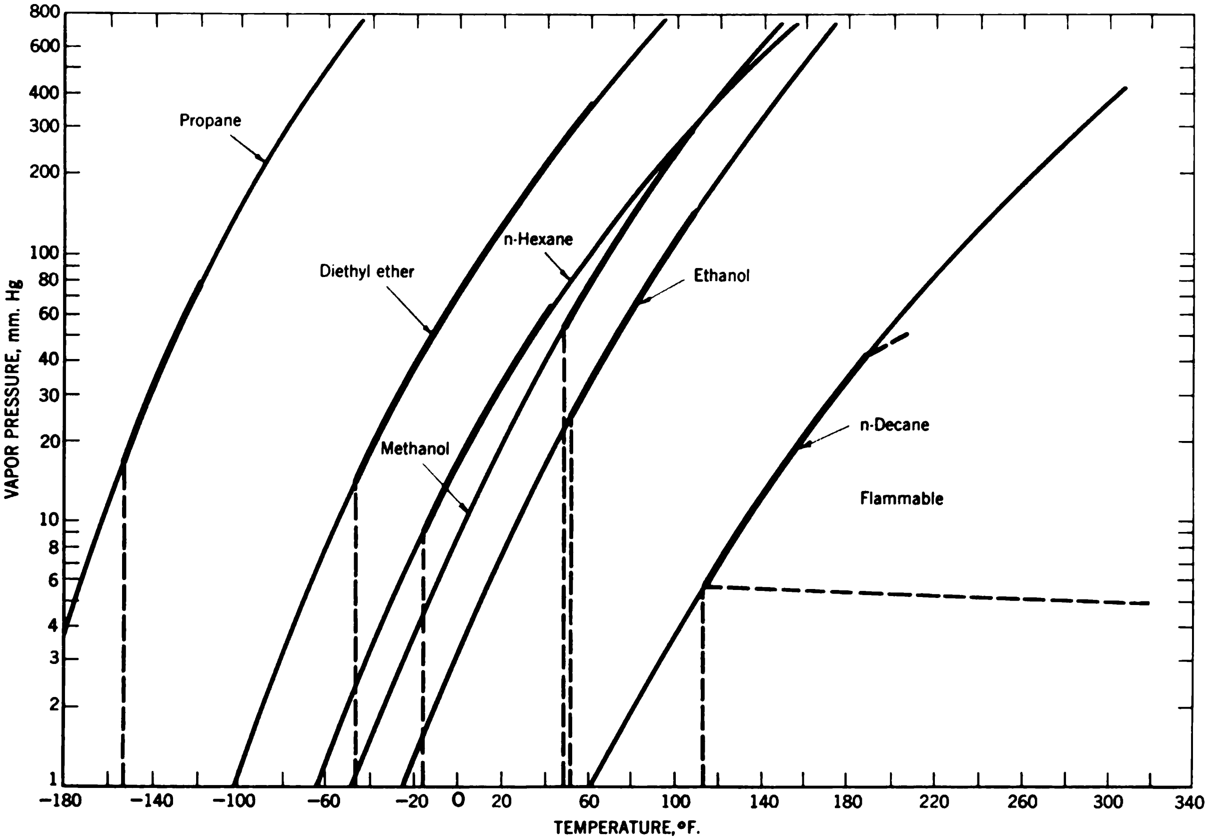

FIGURE 1. - Vapor Pressures of Propane, Diethyl Ether, n-Hexane, Methanol Ethanol and n-Decane.

To use figure 1, first locate the temperature of interest on the horizontal axis, then move upward to meet the curve of interest, and finally move horizontally from the point of intersection to the vertical axis on which the corresponding vapor pressure appears. Conversely, starting with a particular vapor pressure value, move horizontally to meet the curve of interest, then move downward from the point of intersection to the horizontal axis where the corresponding temperature appears.

The limits of flammability and flashpoints of the substances considered in figure 1 are also listed in table 1. For example, consider the combustible n-decane. In table 1, the flashpoint of this combustible liquid is listed as 115° F. and the lower limit of flammability as 0.75 percent n-decane vapor by volume in air. To see how these values are related, first locate 115° F. on the abscissa in figure 1, then move up along this temperature line until the vapor pressure curve for n-decane is intersected. Next, move horizontally from this point of intersection to the ordinate and read the vapor pressure (5.8 mm. mercury). With this value, the lower limit of flammability of n-decane at atmospheric pressure (760 mm. Hg) is calculated as follows:

$$\text{Lower limit of n-decane} = \frac{5.8}{760} \times 100 \text{ pct.} = 0.75 \text{ pct.}$$

Conversely, knowing the lower limit of flammability (0.75 pct.), figure 1 can be used to determine the flashpoint of n-decane (115° F.).

TABLE 1. - Properties of combustibles and oxidants

Combustible	Vapor pressures, P, mm. of Hg., at T. ° C.[1]										
	1 mm.	5 mm.	10 mm.	20 mm.	40 mm.	60 mm.	100 mm.	200 mm.	400 mm.	760 mm.	Melting point, °C.
Methane.........	-205.9_s	-199.0_s	-195.5_s	-191.8_s	-187.7_s	-185.1_s	-181.4	-175.5	-168.8	-161.5	-182.5
Propane.........	-128.9	-115.4	-108.5	-100.9	-92.4	-87.0	-79.6	-68.4	-55.6	-42.1	-187.1
Hexane..........	-53.9	-34.5	-25.0	-14.1	-2.3	+5.4	15.8	31.6	49.6	68.7	-95.3
Decane..........	16.5	42.3	55.7	69.8	85.8	95.5	108.6	128.4	150.6	174.1	-29.7
Methanol........	-44.0	-25.3	-16.2	-6.0	+5.0	12.1	21.2	34.8	49.9	64.7	-97.8
Ethanol.........	-31.3	-12.0	-2.3	8.0	19.0	26.0	34.9	48.4	63.5	78.4	-112
Diethyl ether...	-74.3	-56.9	-48.1	-38.5	-27.7	-21.8	-11.5	42.2	17.9	34.6	-116.3

Combustible	Molecular weight	Vapor density, air=1	ΔH_v, B.t.u./lb.	ΔH_c, B.t.u./lb.	Flash-point ° F.	Lower limit		Upper limit		Spontaneous ignition temperature, ° F.
						Pct.	Combustible oz./cu.ft.	Pct.	Combustible oz./cu.ft.	
Methane........	16.0	0.55	220	21,500	-	5.0	0.038	15	0.13	999
Propane........	44.1	1.53	183	19,930	-	2.1	.043	9.5	.20	871
n-Hexane.......	86.2	2.98	157	19,230	-15	1.2	.046	7.4	.31	478
n-Decane.......	142.3	4.92	155	19,020	115	.75	.048	5.4	.36	406
Gasoline, Grade 100.....	130	-	-	19,000	> 112	1.4	.048	7.6	.30	824
Kerosine.......	-	-	-	18,500	> 113	.7	.048	4.8	.35	444
Methanol.......	32.0	1.11	502	8,640	54	6.7	.052	37	.41	867
Ethanol........	46.1	1.60	396	11,600	55	3.3	.046	19	.32	738
Diethyl ether..	74.1	2.56	151	15,840	-49	1.8	.049	37	1.5	345

Oxidant	Molecular weight	Vapor density, air=1	Melting point, ° F.	Boiling point, ° F.
Oxygen..............	32.0	1.11	-360	-297
Air.................	28.9	1.00	-	-
Nitric acid.........	63.0	2.18	-44	187
Nitrogen dioxide....	46.0	1.59	-15	70
Chlorine............	70.9	2.45	-152	-29
Fluorine............	38.0	1.31	-369	-305

[1] Stull, D. R., Vapor Pressure of Pure Substances-Organic Compounds: Ind. Eng. Chem., vol. 39, 1947, pp. 517-550.

Note.- s = solid.

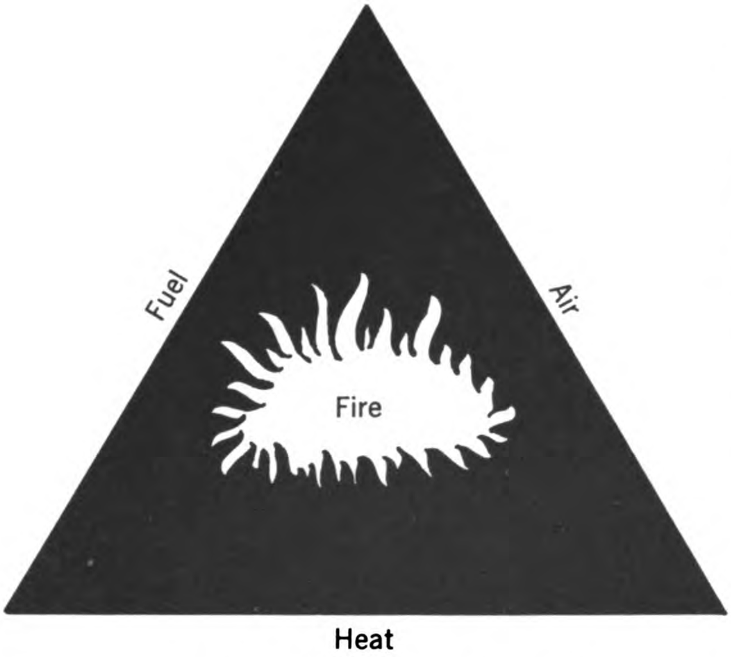

FIGURE 2. - The Fire Triangle.

As a second example of the foregoing procedure, the flashpoint of propane can be determined. The lower limit of flammability of propane is listed as 2.1 volume-percent in table 1. This is equivalent to a vapor pressure of $\frac{2.1}{100}$ x 760 or 16 mm. of mercury. Figure 1 shows that propane has a vapor pressure of 16 mm. at minus 153° F., which should be the approximate[5] flashpoint of this material.

FIRE TRIANGLE

Thus far, only the formation of flammable or explosive vapor-air mixtures has been considered. To start an explosion in such mixtures it is necessary to introduce an ignition source, such as an open flame, a spark, an arc, a hot object, or a shock wave. To visualize better the interrelation of fuel vapor, air, and ignition source, safety engineers have introduced the concept of the fire triangle (fig. 2). In general, a fire will not burn and a flame will not propagate through an explosive mixture until all three "sides" of the fire triangle are present. The removal of any side of the triangle causes it to collapse, thus extinguishing the fire. For example, consider a burning candle. The vaporized wax from the candle is the fuel, air is available from the atmosphere to combine with this fuel, and a match can serve as the ignition source (heat). These points are readily demonstrated as follows:

Demonstration 1. - Collapse of the fire triangle:

(a) The "fuel-side" can be removed by permitting the candle to burn until the wax has been consumed.

(b) The "air-side" can be removed by covering the candle with an air-tight enclosure such as a tumbler.

(c) The "heat-side" can be removed by eliminating all ignition sources.

As the fire triangle is of considerable importance, consider each of the three sides in detail. First, consider the fuel. To assess the hazards of a particular fuel thoroughly all its pertinent properties must be known. The most important are: (1) Vapor pressure, (2) volatility, (3) vapor density, and (4) explosive range (a) flashpoint and (b) fire point.

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[5] In practice, the limits of flammability of a substance are affected by temperature. As the lower limit of flammability of propane (2.1 pct.) was determined at 70° F., this flashpoint value is probably a little too low.

The terms "vapor pressure" and "volatility" are considered briefly in 46 CFR 146. A simple demonstration shows the effect of these properties on the flammability of specific vapor-air mixtures:

Demonstration 2. - Flammability of kerosine, gasoline and JP-4 (jet fuel) vapors in air at room temperature (fig. 3):

At 80° F., the kerosine vapor-air mixture that exists above the liquid (fig. 3) cannot be ignited by passing a flame or spark through it, as the vapor concentration is below the lower limit of flammability. At the same temperature, the gasoline vapor-air mixture immediately above the surface cannot normally be ignited[6] as the vapor concentration is

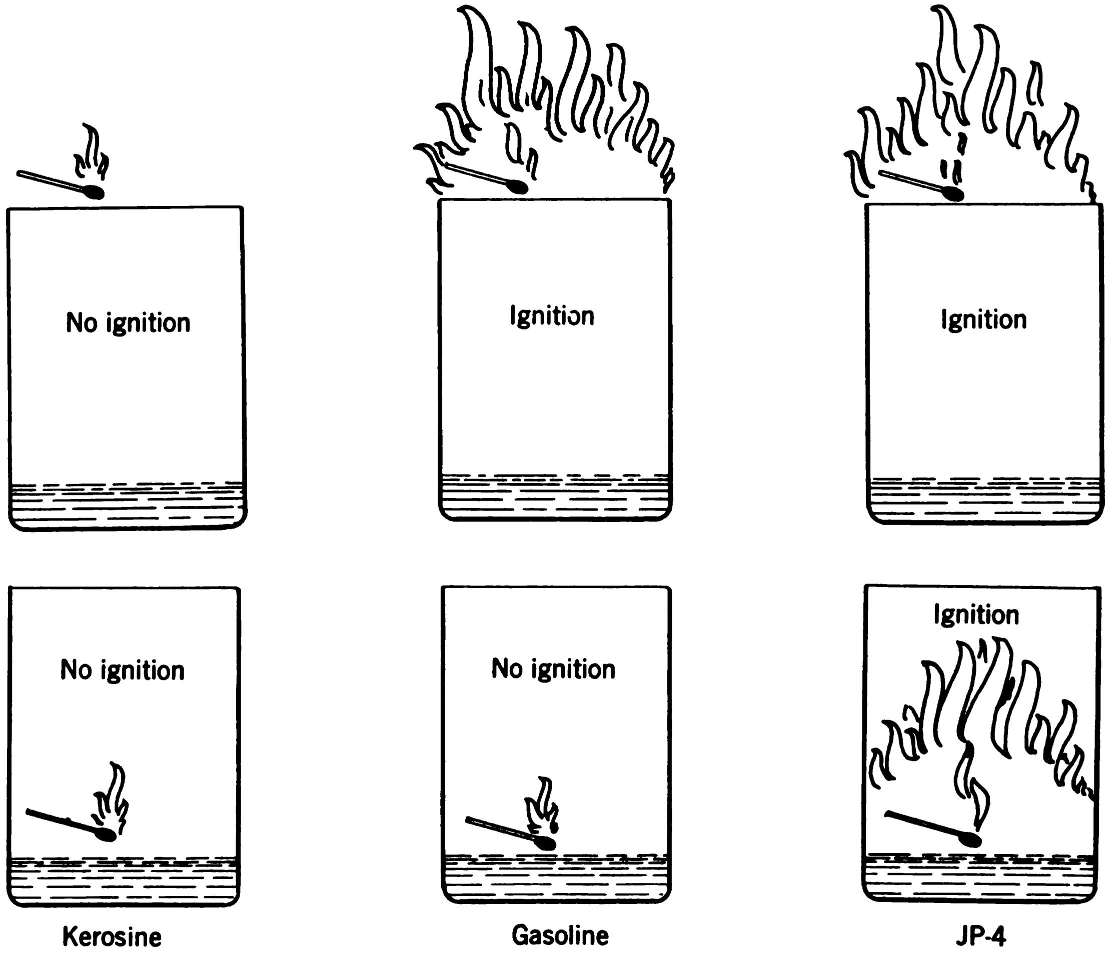

FIGURE 3. - Schematic Demonstration of the Presence or Absence of Flammable Vapors Above Kerosine, Gasoline and JP-4 Fuel at Room Temperature.

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[6] This test should be conducted with a spark and not an open flame since the vapors would be ignited near the top of the container as noted in figure 3.

above the upper limit of flammability, but the JP-4 vapor-air mixture is readily ignited. By raising the ignition source (for example, a flame) the kerosine vapor-air mixture cannot be ignited near the top of the container, whereas the vapors can be ignited near the tops of the gasoline and JP-4 containers. In brief, the vapor pressure of kerosine is so low that flammable vapor-air mixtures are not formed above this liquid at ordinary room temperatures (about 80° F.), whereas the vapor pressure of gasoline is so high that flammable mixtures are not formed immediately above the liquid but are formed near the top of the open container, because the vapors there are diluted readily with air. On the other hand, the vapor pressure of JP-4 jet fuel is adequate to permit the formation of flammable mixtures within the container.

Vapor density is defined (sec. 146.03-35) as "the relative density of the vapor given off by an inflammable liquid (that is, a flammable liquid) as compared with air." The hazards of vapors with density greater than that of air are readily demonstrated as follows:

Demonstration 3. - Vapor density (figs. 4, 5, 6):

First, carefully saturate a small amount of cotton waste with unleaded gasoline or naphtha and place it at the top of a 6-foot trough (fig. 4). As gasoline vapor is several times heavier than air, an open flame just above the waste will not ignite the gasoline vapor-air mixtures that form as the gasoline vaporizes, but an open flame below the waste will ignite the mixtures shortly after the waste is placed near the top of the trough

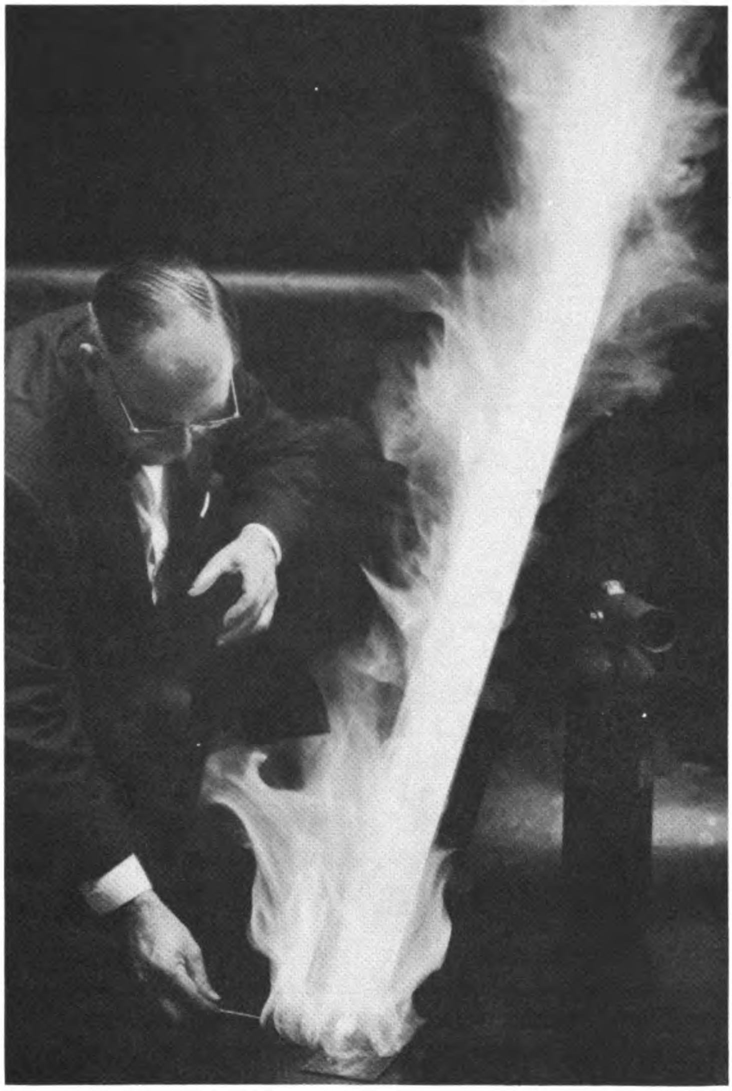

FIGURE 4. - Propagation of Flame up a Trough Containing Unleaded Gasoline Vapors Released by Gasoline-Soaked Cotton Waste Placed Near the Top of the Trough.

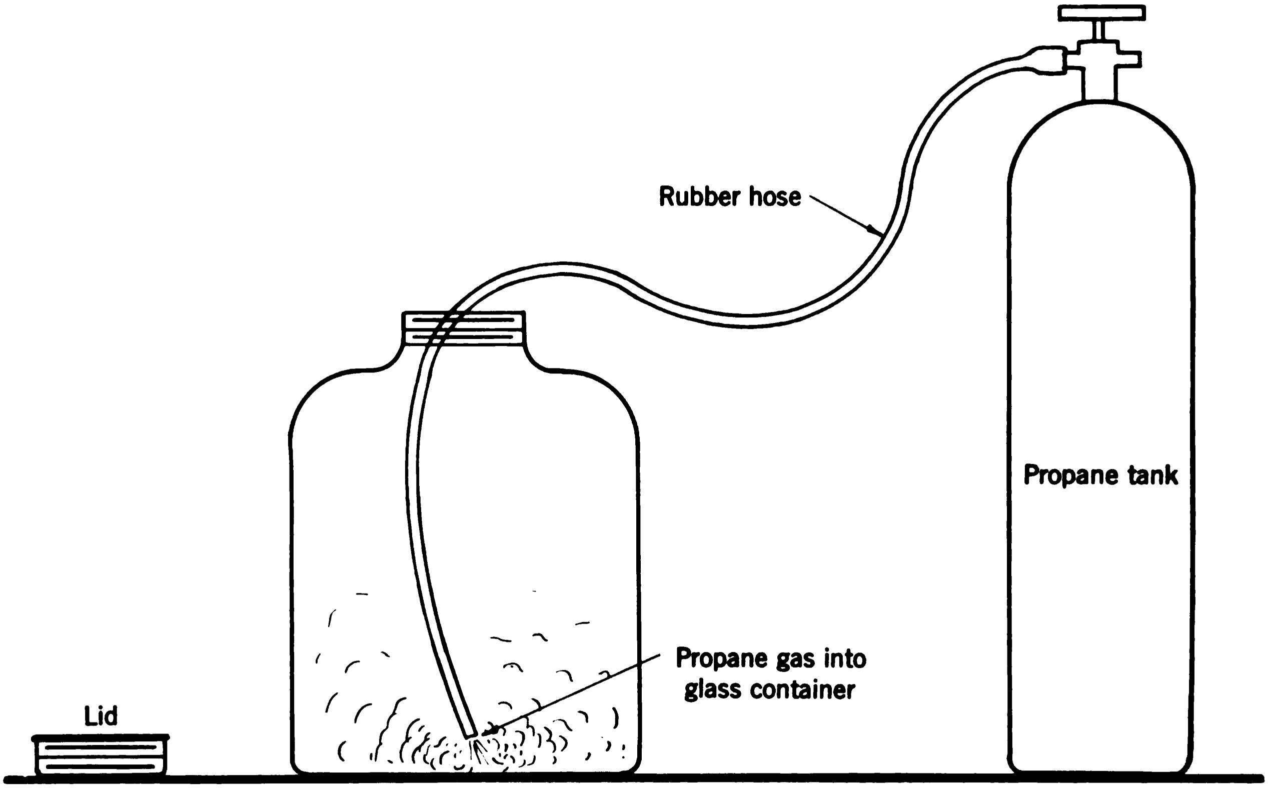

FIGURE 5. - Schematic Diagram of the Apparatus Used to Fill a Glass Container With Propane Gas.

(fig. 4). A short period of time is required for the vapor to flow down the trough. (During this experiment it is well to have a fire extinguisher handy, as the flame will flash back and ignite the waste.)

Next, take a wide-mouth gallon bottle that has been previously filled[7] with propane or butane gas from a tank of the compressed gas (fig. 5). The bottle appears to contain only air; however, when it is emptied into an inclined trough (fig. 6) which has a lit candle at its base, a flame flashes from the candle to the "empty" bottle after a few seconds. This experiment again illustrates the hazards associated with a heavier-than-air combustible gas that can flow down to an ignition source.

Explosive range (sec. 146.03-10) is the range of flammable fuel vapor compositions in air at atmospheric pressure and ordinary temperatures. Flame propagates away from an ignition source only in mixtures within the explosive range. The effects of passing an open flame through fuel vapor-air mixtures with compositions below the lower limit, at the lower limit, within the

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[7] To fill the bottle the gas should be passed into it slowly until the air has been displaced; the rubber hose should then be withdrawn slowly and the bottle capped and set aside until it is needed.

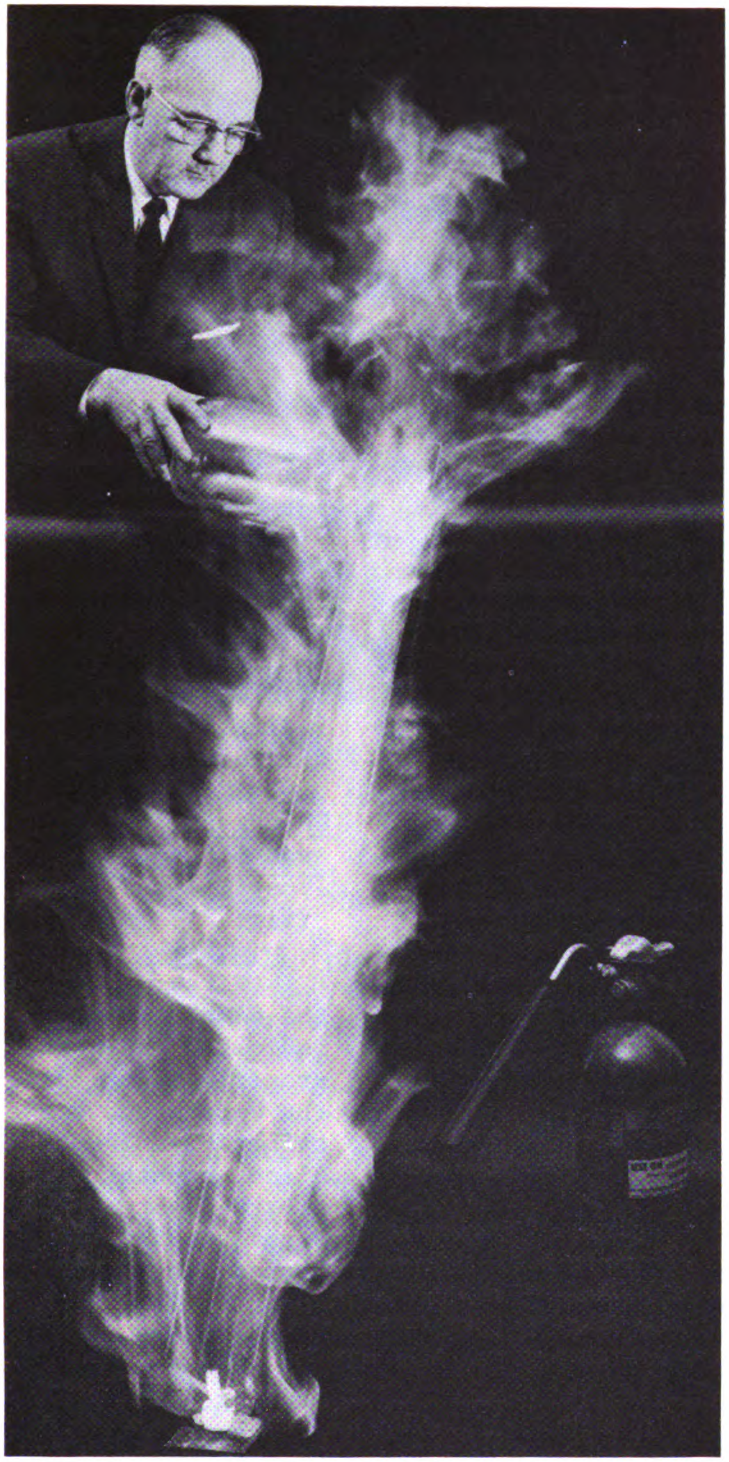

FIGURE 6. - Propagation of Flame up a Trough Containing Propane Vapors "Poured" Into the Upper End of the Trough. The Candle at the Base of the Trough Ignited the Vapors.

explosive range, at the upper limit, and above the upper limit can be demonstrated by using a flame propagation tube.[8]

Demonstration 4. - Flame propagation in propane-air mixtures (fig. 7):

The desired test mixtures are made by passing propane and air into a vertical glass pipe; calibrated flowmeters are used to obtain mixtures containing 1.0, 2.1, 4.0, 9.5, and 12 volume-percent propane. Only those between 2.1 and 9.5 volume-percent propane will propagate a flame. An open flame at the base of the tube ignites the flammable mixtures. (Safety glasses should ordinarily be worn when conducting such tests in glass apparatus!)

The Cleveland flashpoint tester is used to determine the flashpoint of a liquid. It is a fairly simple apparatus consisting essentially of a cup, a heater, a test flame, and a thermometer. Its use can be illustrated by determining the flashpoint of oil.

Demonstration 5. - Cleveland open-cup flashpoint apparatus (fig. 8):

Fill the cup with an oil to the specified level

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[8] Engel, Hal H., and Merritts, W. M., Lecture and Demonstration on Flame Propagation and Permissible and Explosion-Proof Electrical Equipment: Bureau of Mines Inf. Circ. 7980, 1960, 13 pp.

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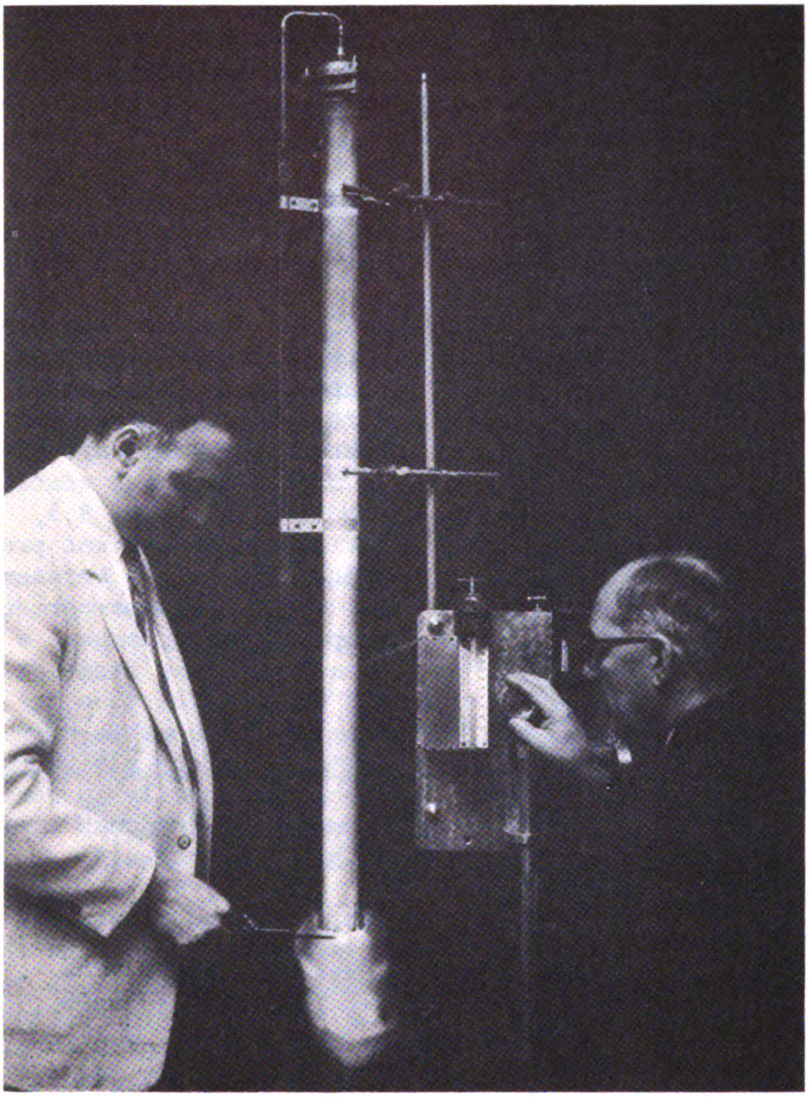

FIGURE 7. - Flame Propagation Through a Propane-Air Mixture in a Vertical Tube. The Open Flame at the Base of the Tube Ignited the Mixture.

and heat it at the rate of about 10° F. per minute. Introduce the test flame momentarily into the vapor space of the cup as the oil is heated. Repeat after each 5° F. rise in temperature until a distinct flash is observed in the vapor space; the flashpoint is the lowest temperature at which such a flash occurs. After demonstrating that the oil vapor in the flashpoint apparatus is flammable, the vapors should be tested with a commercial hot-wire-type combustible gas indicator, as noted in demonstration 6.

Demonstration 6. - Use and misuse of a combustible gas indicator (fig. 8):

First, show that the combustible gas indicator[9] is working properly by sampling the vapors above a container of unleaded gasoline, naphtha, or cigarette-lighter fluid. Purge the instrument and test the flammable vapors above the oil in the heated Cleveland tester. The combustible gas indicator shows that the mixture is nonflammable. (In figure 8, the oil vapors were sampled just before they were ignited.) As the tubing and the meter are at a lower temperature than the oil, the vapors from the tester condense on the walls of the tubing. This effect could have been predicted by considering the effect of temperature on vapor pressure (fig. 1). The demonstration again shows the importance of knowing the properties of a fuel in determining its hazards. Strangely enough, vapor-air explosions have been caused by the false safety induced by a combustible gas indicator that has been misused in this manner.

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[9] Use an indicator with the active filament in the case in which the meter is located and with flexible tubing to draw the atmosphere to be tested past the filament.

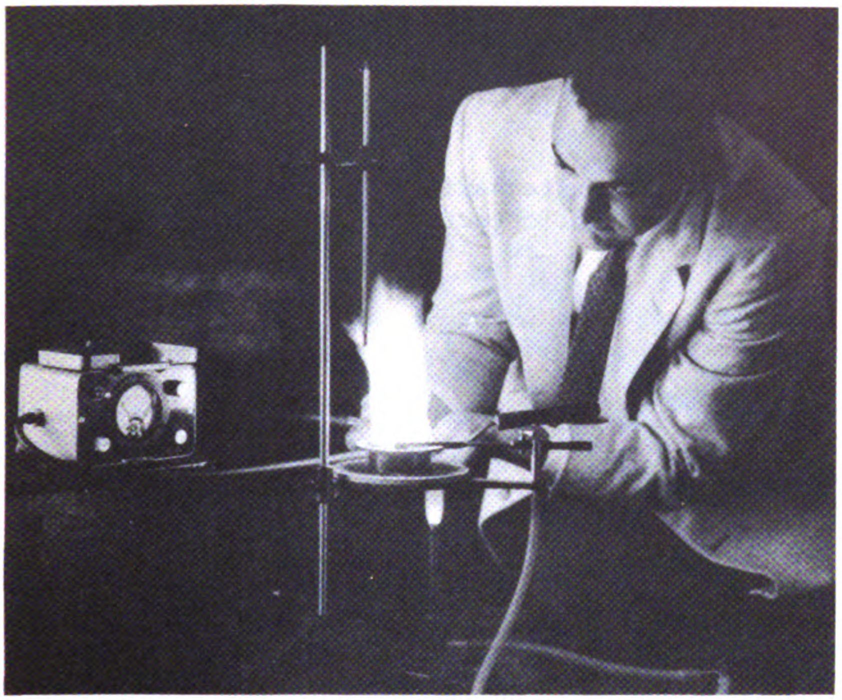

FIGURE 8. - Cleveland Open-Cup Flashpoint Apparatus.

Although air (actually, the oxygen in the air) is the most common oxidant in use today, other oxidants such as chlorine and nitric acid, are used in special cases. Table 1 summarizes the properties of several oxidants. In the next demonstration, note what happens when nitric acid is used as the oxidant instead of air in a special experiment with one of the fuels used in missile work.

Demonstration 7. - Spontaneous ignition of unsymmetrical dimethylhydrazine (UDMH) in nitric acid (fig. 9):

Carefully place five drops of UDMH in a test tube mounted on a ring strand. Then, rapidly add a few drops of nitric acid and quickly remove the medicine dropper or pipette used to add the acid. The combination, UDMH plus nitric acid, ignites almost instantly (fig. 9). Do not breathe the vapors that are formed after this combustion reaction.

This demonstration illustrates an important consideration in storing certain materials--compatibility. Materials that react when combined accidentally or otherwise should not be stored next to each other. Specifically, nitric acid being a corrosive liquid must be handled in accordance with the regulations given in section 146.23.

The first seven demonstrations were designed to illustrate different properties of fuels and oxidants. Ignition sources were used to start fires with various fuel-oxidant combinations. However, as an ignition source is required to complete the third side of the fire triangle, it is well to consider such sources in some detail. The most common sources are:

1. Flames (matches, cigarette lighters, gas flames, and so forth).
2. Sparks (electrical discharges, electrical shorts, and lightning).

3. Hot objects (glowing filaments, hot cinders, electric lights, and sparks from tools).

4. Shock waves.

Open flames and sparks were used to ignite various flammable mixtures in the preceding demonstrations. Sparks and hot objects will be used as ignition sources in the following experiments.

Demonstration 8. - Explosion-proof and nonexplosion-proof motors and other electrical appliances (fig. 10):

The hazards associated with the operation of nonexplosion-proof equipment in a flammable atmosphere are readily illustrated by the use of the explosion gallery shown in figure 10. The equipment to be tested (doorbell, electric motor, and so forth) is first placed in the gallery which is then sealed with a paper diaphragm. Next, a flammable propane-air mixture is introduced into the gallery and voltage is applied to the equipment being tested. A nonexplosion-proof equipment will ignite the flammable mixture and rupture the paper diaphragm (as shown in fig. 10). A properly maintained explosion-proof equipment will not ignite the flammable mixture.

So far, only fuel vapors and gases have been considered. However, it is well known that combustible mists and dusts can also produce disastrous explosions. The next demonstration is designed to illustrate the hazards of mists and dusts.

Demonstration 9. - Kerosine foam and combustible dust (figs. 11-13):

When a spark is passed through the vapor above a liquid pool of kerosine, an ignition does not occur if the temperature of the kerosine is below its flashpoint (fig. 3). However, foam and mist can be ignited above a kerosine pool at temperatures below the flashpoint. This ignition may result in an explosion if enough foam and mist are present in a closed container (fig. 11). Similarly,

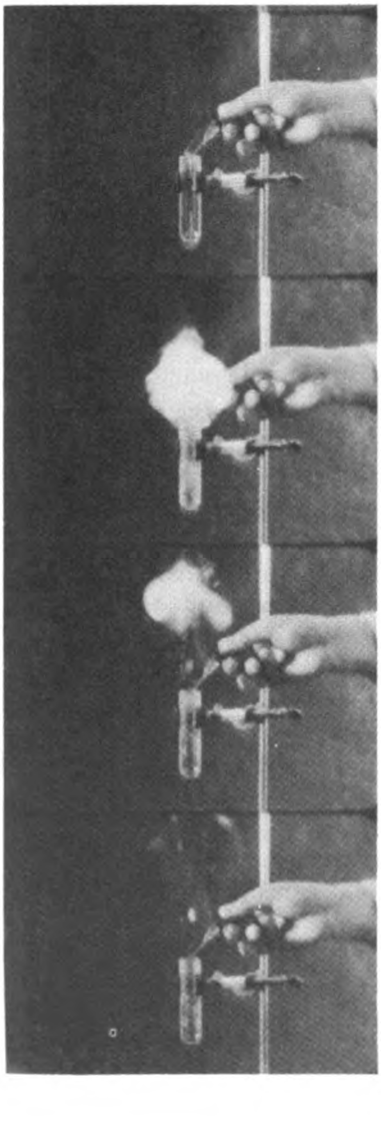

FIGURE 9. - Spontaneous Ignition of UDMH (unsymmetrical dimethythydrazine) in Nitric Acid at Room Temperature. Sequence, Taken at the Rate of 16 Frames per Second, Begins With Top Frame.

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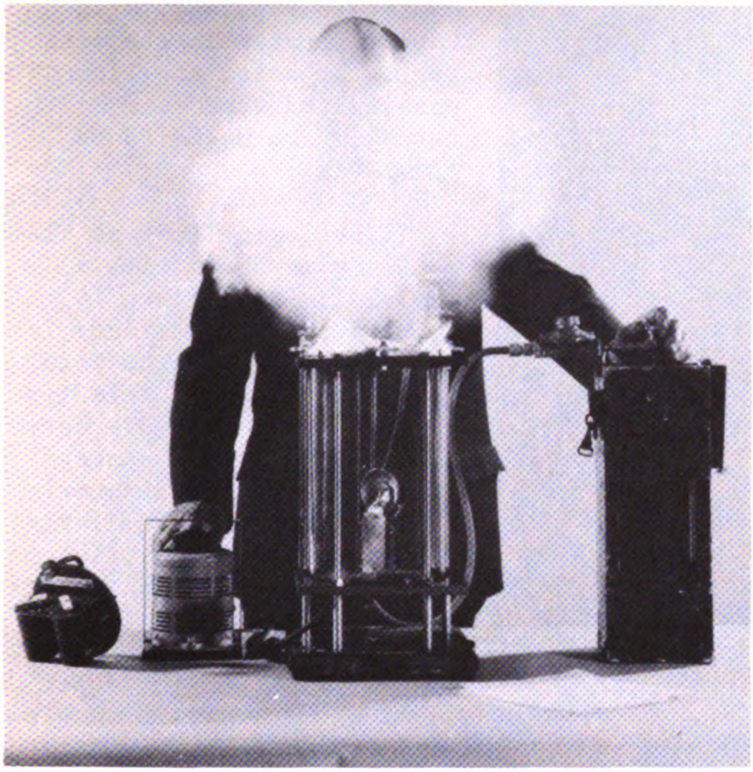

FIGURE 10. - Ignition of a Propane-Air Mixture in a Glass Explosion Gallery by a Nonexplosion-Proof Doorbell.

combustible dust can also be ignited when it is dispersed in the air. In this connection it must be remembered that dusts directly derived from organic materials are combustible. In addition, many minerals and metals produce ignitable dusts (for example, coal, aluminum, titanium, and magnesium).

The apparatus shown in figure 12 may be used to demonstrate the hazards associated with the production of fine dusts in the air. This figure shows a cloud of coal dust that was just ignited by a hot wire; figure 13 shows a cloud of aluminum dust ignited in the same manner. The dust clouds are formed by dispersing the dust in the explosion chamber after a wire in the chamber has been heated to incandescence. Some materials (for example, powdered sugar) can be ignited at fairly low hot-wire temperatures. After the wire is incandescent, it should be allowed to cool until it becomes nonluminous before the powdered sugar is dispersed into the air. If the temperature of the filament is above that required to ignite the sugar (that is, above the spontaneous ignition temperature), an explosion will result.

The concept of a spontaneous ignition temperature was introduced in demonstration 9. This is the temperature required to ignite a combustible vapor, mist, or dust in air. Below this temperature, an external ignition source (flame, spark, and so forth) must be used; above this temperature, an external source is not needed. This concept is illustrated further in figure 14, which summarizes many of the items considered thus far. The solid curve labeled "Saturated Mixtures" is the vapor pressure curve for n-decane. The composition of a saturated n-decane vapor-air mixture may be found by first determining the vapor pressure at the temperature of interest, then dividing this by the total system pressure (the barometric pressure for a system in which n-decane is exposed to the atmosphere). Supersaturated mixtures can exist in special cases at temperatures below the saturation temperature; however, at such temperatures some of the vapor usually condenses and forms a mist; this is the region labeled "Mist" in the figure. As an ignition source can cause

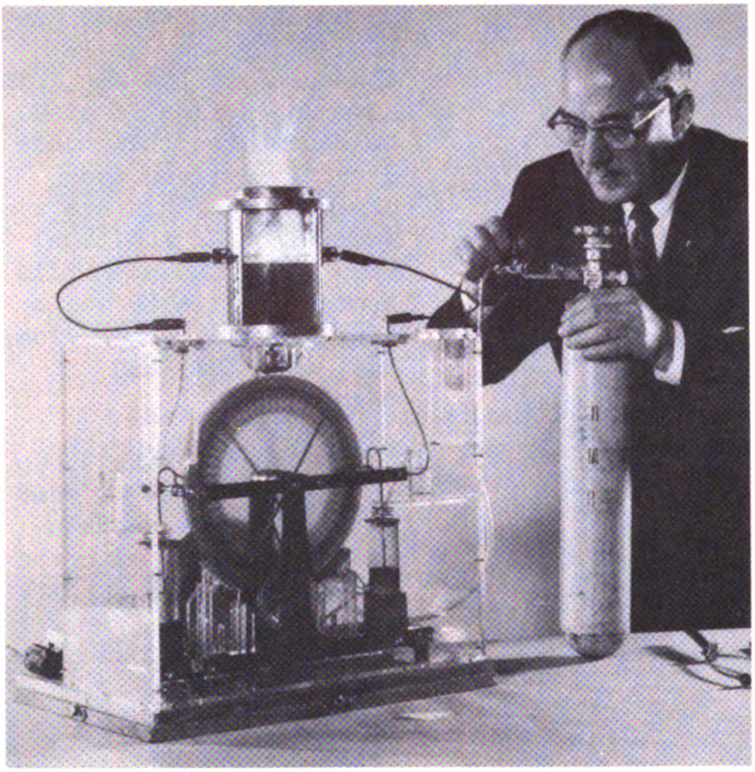

FIGURE 11. - Ignition of Kerosine Foam at Room Temperature.

a mist to vaporize, mist-vapor mixtures in the mist region opposite the flammable unsaturated vapor-air mixtures region may also be flammable.

The lower limit of flammability is shown with a broken line in figure 14. As already note, it extends into the mist region. The point of intersection of this line and the vapor-pressure curve is the lower temperature limit, T_L, and the approximate flashpoint. Similarly, the point of intersection of the upper limit of flammability and the vapor pressure curve is the upper temperature limit, T_U. The upper limit of flammability has not been extended into the mist region, as there is no clear-cut indication that an upper limit exists.

All n-decane vapor-air mixtures between the upper and lower limit of flammability curves and to the right of the vapor pressure (saturated mixtures) curve are flammable. However, an ignition source is required to start flame propagation below the temperatures along the spontaneous ignition curve. At temperatures to the right of those along this curve, ignition occurs spontaneously after a certain time delay; that is, ignition is spontaneous but not instantaneous. The time delay before ignition depends on the n-decane concentration, the pressure, the temperature, and in some instances, the geometry and dimensions of the hot surface.

APPLICATIONS

Now that the basic items needed to evaluate the hazards associated with certain dangerous articles (flammable liquids, and so forth) have been considered, some important applications are discussed to see how the basic information may be used.

1. Fire Extinguishment:

The fundamentals of fire extinguishment were discussed briefly in demonstration 1. Many excellent publications are available in this

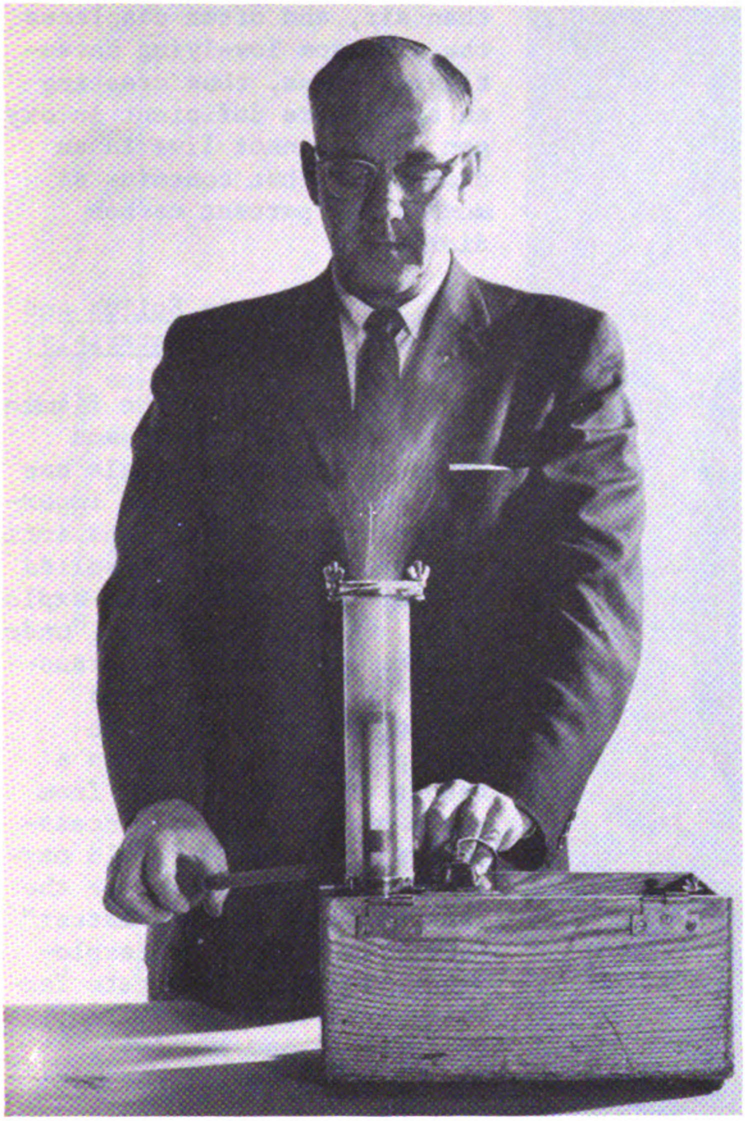

FIGURE 12. - Hot-Wire Ignition of Coal Dust Dispersed in Air.

field.[10-12] The principal extinguishing agents in use today are water, dry chemical, carbon dioxide, and halogenated hydrocarbons. Water is most often used directly, in a liquid stream or a spray, to cool the fuel. However, it can also be used in the form of steam or as foam to blanket the fuel and thus effectively remove the air side of the fire triangle. The other agents can act much the same as water. However, the effectiveness of the dry chemical (principally sodium bicarbonate) and halogenated hydrocarbons is enhanced by their tendency to react with the products formed in the burning process.[13] Therefore, these materials are quite effective extinguishing agents.

2. Gas freeing:

The gas freeing of cargo tanks has been considered in some detail in a recent publication.[14] Tanks are gas freed for various reasons such as periodic cleaning, tank inspection or repairs, and change of cargo. In this connection, it is well to determine the nature of the atmosphere in the tank or in any unventilated space before entering it. Remember that many flammable vapors are heavier than air (demonstration 3). Carbon dioxide is an inert gas, heavier

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[10] Crosby-Fiske-Forster; Mounton, Robert S., ed., NFPA Handbook of Fire Protection: Nat. Fire Protection Assoc., Internat., Boston, Mass., 1947.

[11] National Fire Protection Association, International, The National Fire Codes. Volume IV, Extinguishing Equipment: Boston, Mass., 1957.

[12] Armistead, George, Jr., Safety in Petroleum Refining and Related Industries: John G. Simmonds & Co., Inc., New York, N. Y., 1950.

[13] Guise, A. B., Chemical Aspects of Fire Extinguishment: Ind. Eng. Chem., vol. 51, 1959, pp. 73A-75A.

[14] Zabetakis, M. G., Gas Freeing of Cargo Tanks: Bureau of Mines Inf. Circ. 7994, 1960, 10 pp.

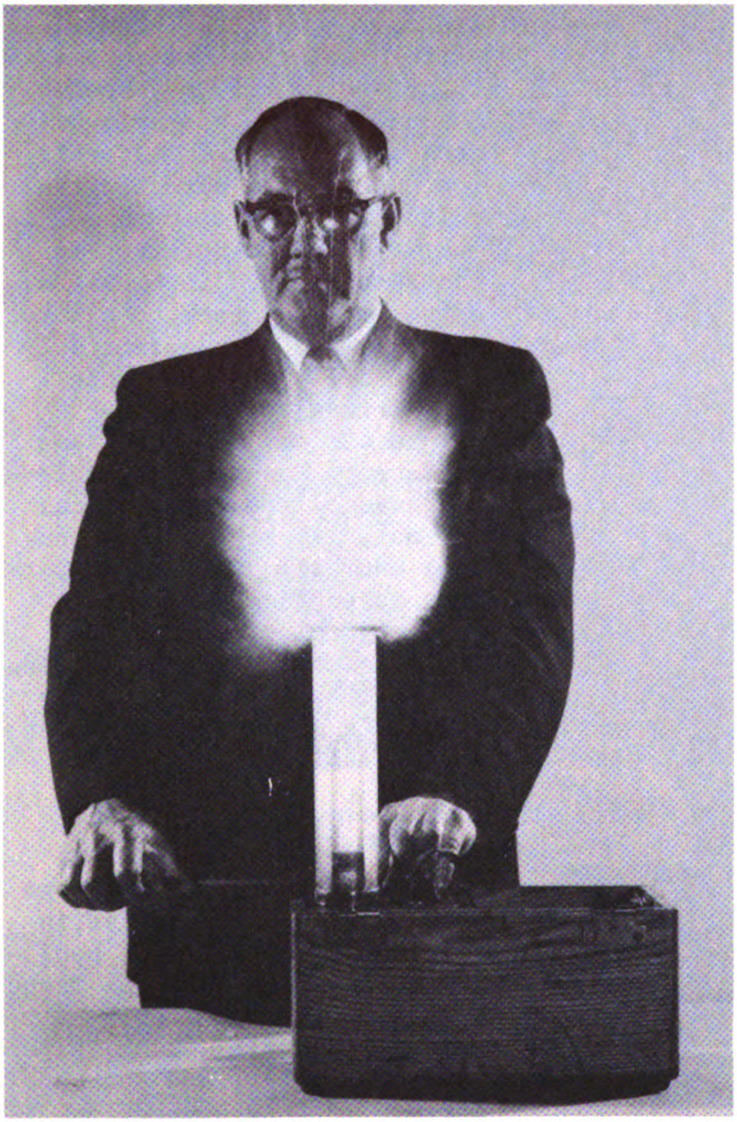

FIGURE 13. - Hot-Wire Ignition of Aluminum Dust Dispersed in Air.

than air, and often displaces the air from low-lying unventilated areas, thus creating an atmosphere deficient in oxygen. Man cannot live in an atmosphere that contains as much as 10 percent carbon dioxide.[15]

3. Flammable Solids and Oxidizing Materials:

Thus far, only the flammability of fuels in air and other oxidizing materials has been considered. Other important classes of dangerous articles are the flammable solids and materials other than explosives, which are liable, "under conditions incident to transportation, to cause fires through friction, through absorption changes, or as a result of retained heat from the manufacturing or processing" and those that yield oxygen readily "to stimulate the combustion of organic matter" (sec. 146.22-1). The explosions of ammonium nitrate fertilizer at Texas City, Tex., on April 16 and 17, 1947,[16] demonstrated one of the hazards of materials of this class. Furthermore, the numerous fires started by these materials add importance to their study. Because of the variety of properties associated with these articles, it is well to review the contents of table E, section 146.22-100, in detail.

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[15] Forbes, J. J., and Grove, G. W., Mine Gases and Methods for Detecting Them: Bureau of Mines Miners' Circ. 33, 1954, 82 pp.

[16] Kintz, G. M., Jones, G. W., and Carpenter, Charles B., Explosions of Ammonium Nitrate Fertilizer on Board the SS Grandcamp and SS High Flyer at Texas City, Tex., April 16, 17, 1947: Bureau of Mines Rept. of Investigations 4245, 1948, 57 pp.

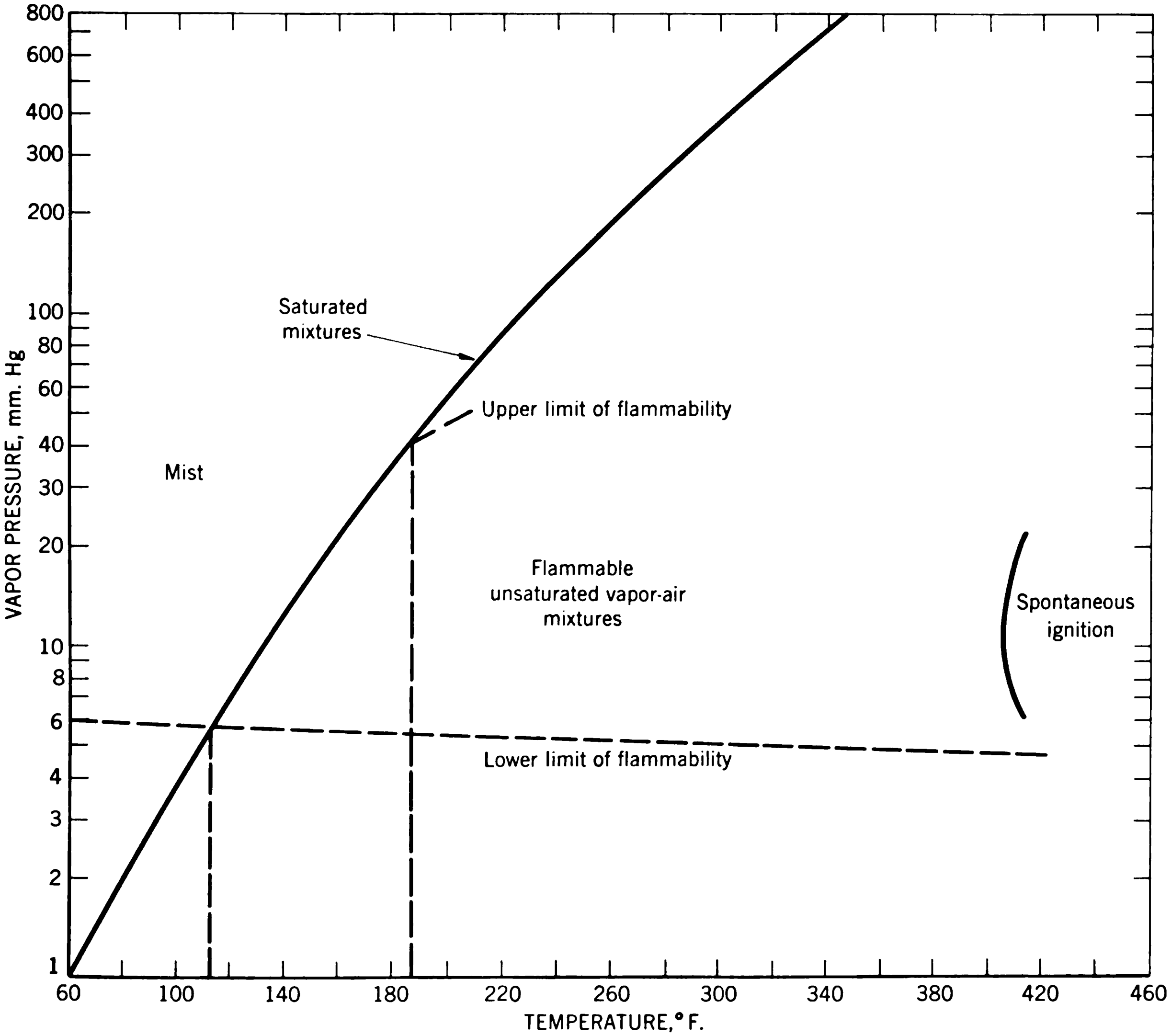

FIGURE 14. - Flammability Diagram of n-Decane in Air at 1 Atmosphere Pressure.

4. **Detection Equipment:**

The use and misuse of a combustible gas indicator was discussed in demonstration 6. Two recent publications[17] [18] give additional information on such indicators and on detectors for use in atmospheres containing carbon monoxide, carbon dioxide, hydrogen sulfide, sulfur dioxide, and oxygen. Before a particular detector is used, its limitations should be considered carefully. For example, most combustible gas indicators do not show the oxygen concentration of the atmosphere. Many deaths have resulted upon entry in an area containing an oxygen-deficient atmosphere which had first been tested with a combustible gas indicator and found to be "gas free."

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[17] Work cited in footnote 15.

[18] Beatty, R. L., Methods for Detecting and Determining Carbon Monoxide: Bureau of Mines Bull. 557, 1955, 34 pp.